Annals of Warsaw University of Life Sciences – SGGW
Forestry and Wood Technology № 121. 2023: 135-141
(Ann. WULS - SGGW, For. and Wood Technol. 121, 2023: 135-141)
Received: 18.07.22 / Accepted: 02.03.23 / Published: 29.03.23

Relationship between the compressive strength, density and the width of the annual rings in a high-guality part of timber of Scots pine (*Pinus sylvestris* L.) wood

PATRYCJA ZATOŃ, PIOTR MAŃKOWSKI, PAWEŁ KOZAKIEWICZ

Department of Wood Science and Wood Preservation, Institute of Wood Sciences and Furniture, Warsaw University of Life Science – SGGW

Abstract: *Relationship between the compressive strength, density and the width of the annual growth ring in a high-quality part of a timber of Scots pine (Pinus sylvestris L.) wood.* The wood species being used the most often in Poland have been the coniferous wood of Scots pine (*Pinus sylvestris* L.). The following article made an attempt to determine the mechanical properties of Scots pine wood based on certain physical parameters. It was found that the relationship between the width of the annual growth ring and the compressive strength along the fibres was not established. Also, the share of late wood of Scots pine was approximately constant in the whole studied density range and amounted to approximately 50%. The compressive strength along the fibres increased together with wood density. No relation was found between the width of the annual growth ring and the compressive strength along the fibres.

Keywords*: Scots* pine wood, sawn timber for general use, compressive strength, wood density, late wood

INTRODUCTION

Scots pine (*Pinus sylvestris* L.) is a naturally occurring conifer species in Europe, Asia Minor and Central and Northern Asia, except in high mountain areas. Scots pine takes up about 60% area of Polish forests [Forests in Poland, 2018]. It is the most important forest species in Poland and at the same time the most crucial industrially processed wood species with a very wide range of applications [Galewski and Korzeniowski 1958; Kozakiewicz and Krzosek, 2013; Borysiuk et al. 2019; Kozakiewicz, 2019]. At the same time, it is a species with a high variability of features that make processing difficult, hence the search for correlation between the physical and mechanical properties of pine wood, the knowledge of which would facilitate the process of its selection and sorting. The predestined features (references to comparisons) seem to be: the perfectly visible width of annual increments and the proportion of late-wood, as well as easy-to-manufacture and common tests: wood density and its compressive strength along the grain [e.g. Kozakiewicz, 2010; Krzosek and Mańkowski, 2013; Jakubowski et al. 2013; Jankowska and Kozakiewicz, 2014; Chmielowski et al. 2018; Kozakiewicz et al. 2020].Generally, with increasing width of annual increments in pine wood, the share of thin-walled early wood increases, and the width of late-wood remains unchanged. Therefore, broad-grain pine has a lower density and is less durable compared to narrow-grain softwood in which the percentage ratio of late to early wood is higher [Vorreiter, 1949; Dzbeński, 1970; Krzysik, 1978; Kozakiewicz, 2012].

Relationships between the density of the wood of Scots pine and its compressive strength determined for different origins are also known [e.g. Vorreiter, 1949; Dzbeński et al. 2000; Kozakiewicz 2010]. The equations describing these relationships are characterized by various coefficients. The question arises whether these relationships are maintained in a typical batch of material (a typical for commercial and timber warehouses of unknown origin, but meeting the requirements of sawn timber of the indicated class).

The aim of the following study is to check the relationship between the compressive strength along with the fibre and the density as well as the width of annual rings and the proportion of late-wood.

MATERIAL AND METHODS

Wood was selected for the tests from a typical batch of air-dry, planed, edged Scots pine timber for general use (first-class according to PN-D-96000: 1975) with a cross-section of 40 x 140 mm. It was knotless timber, obtained from mature wood from the butt parts of the trunks. Typical for the sale of wood in Polish commercial warehouses is the lack of information about the origin of the wood, i.e. the place where it was harvested in the forest. A twelve timers with a specific grain pattern (standing or lying (not diagonal)) were selected from the entire stack, for the tests. From the entire cross section of each piece of timber was cut standard samples for individual determinations (according to the course of the main directions and anatomical sections). In total, several dozen samples were obtained.

The study of determining the width of annual growth rings was carried out per PN-D-04110:1955 standard. Due to the simultaneous testing of the strength and width of the annual growth rings, the larger samples were used (30x20x45 mm; dimensions in the tangential, radial and longitudinal directions, respectively) to test a greater number of annual growth rings on one sample. Samples with dimensions 30x30x10 mm were grounded and placed on a microscope stage. The results from the micrometre screw were entered into a program specially written for that purpose. Micrometre screw measuring range 0-25 mm, accuracy 0,01mm (Fig.1).

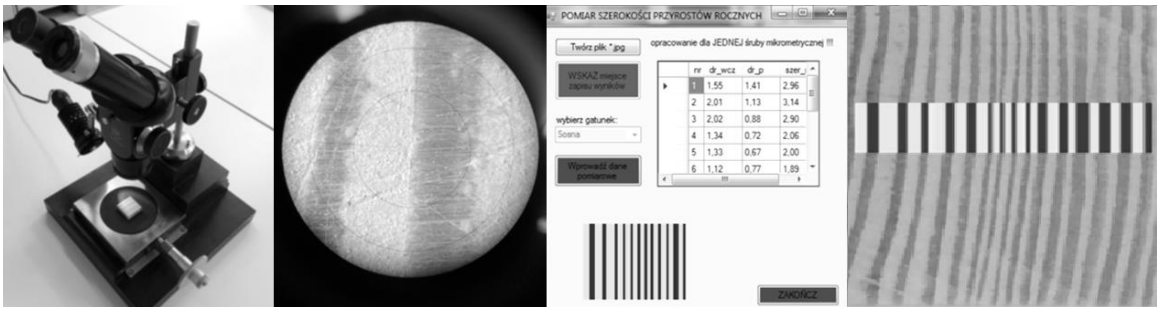

Figure 1. The process of determining the width of annual growth rings

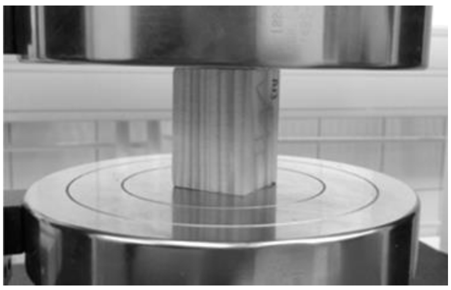

Figure 2. The strength compression test (sample between the disc pressures of the INSTRON testing machine)

Wood moisture content was determined with the dryer-weight method by PN-D-04100:1977 and ISO 13061-1:2014. Wood density was determined by the stereometric method following PN-D-04101:1977 and ISO 13061-2:2014. According to standard, samples for compression tests along the fibres should be a dimension of 20x20x30 mm. The compression test was performed under the PN-D-04102:1979 standard and ISO / DIS 13061-17:2015 standard (Fig. 2). Seventy-two samples were used for each of the tests.

RESULTS AND DISCUSSION

The results of the mean values of the investigated features of pine wood together with the statistical measures are presented in Table 1, and the relationships between the selected features in figures 3-8.

Table1. Investigated properties of Scots pine wood.

Investigated property of wood	Average value	Standard deviation	Coefficent of variation [%]
Moisture content [%]	11.5	0.8	6.9
Width of annual rings [mm]	1.78	0.51	28.5
Share of late wood in annual rings [%]	41.9	5.8	13.8
Density [kg/m^3]	550	31	5.7
Compression strength parallel to garin [MPa]	61.9	13.7	22.1

The investigated pine wood is extremely narrow-grained wood with an average density of 550 kg/m^3, typical for this species [Warywoda, 1957; Galewski on Korzeniowski, 1958; Krzysik 1978; Kozakiewicz, 2012] and showing a relatively low variability of these traits (coefficients of variation at the level of 6.9 and 5.7%) compared to the typical ones, even in one trunk, usually amounting to at least a dozen or so percent [Dzbeński 1884, Fabisiak 2005]. The compressive strength along the fibres of investigating Scots pine wood amounted to 37-74 MPa which was a close value to the value reported by Galewski and Korzeniowski [Dzbeński [1984] (30-80 MPa). The test showed that the average strength of 48 MPa corresponded to the wood density of 517 kg/m^3, which was a value similar to the value stated by Cote and Kollmann [1968] (55 MPa at 530 kg/m^3 of wood density) and it was a lower value than reported Kozakiewicz [2010] (45.9 MPa at 470 kg/m^3] and Tiemann [1951] (89 MPa at the wood density 850 kg/m^3].

Figure 3 shows the relationship between the air-dry wood density and the width of annual rings. When correlating the results with a straight line, a surprising correlation was obtained, which said that the density of pine wood increased with the increase in the width of annual rings, a relationship inconsistent with the general indication that it is exactly the opposite [Krzysik 1978, Dzbeński 1984, Kozakiewicz 2013].

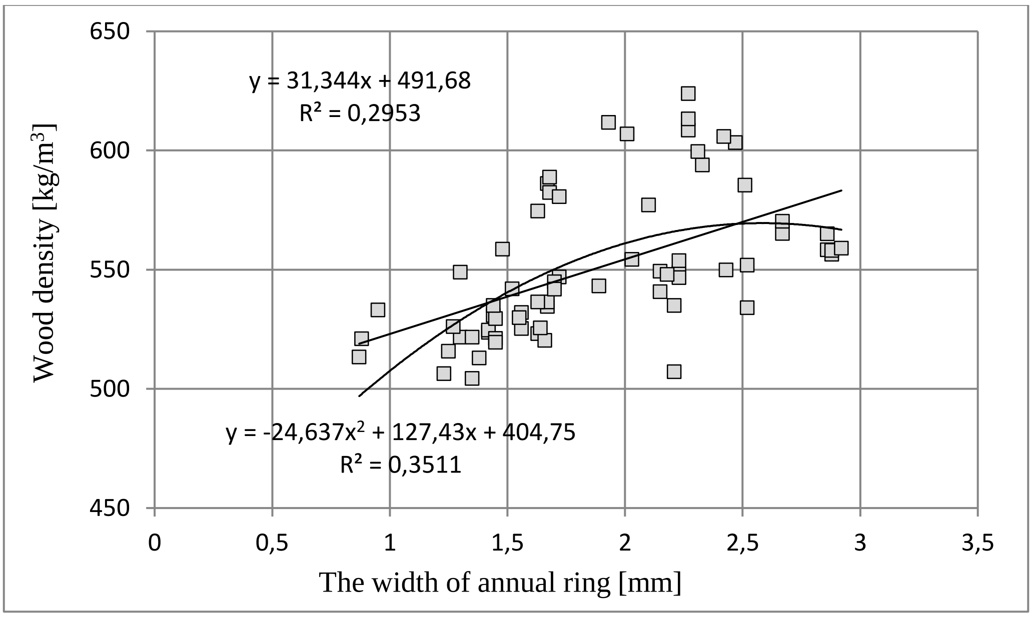

Figure 3. The relationship between the average width of annual growth rings and wood density

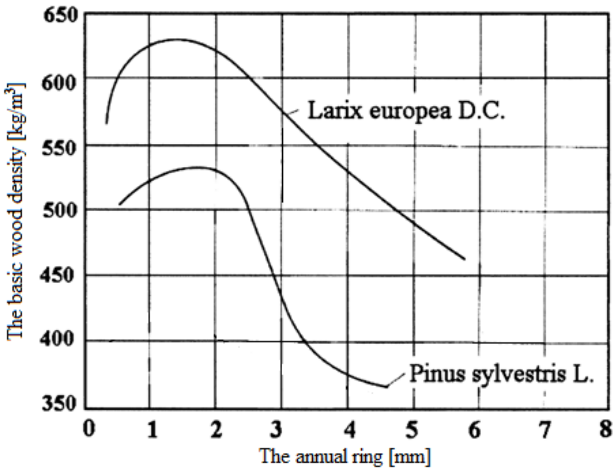

Figure 4. The relationship between the average width of annual growth rings and the basic wood density [developed on the basis of Kollman and Cote, 1984]

The found inconsistency is only apparent, because the examined Scots pine wood was extremely narrow-grained, with a width of annual overgrowths, ranging from about 0.8 mm to 2.8 mm. With such narrow-grained wood, the inversely proportional correlation between density and grain breaks down, as indicated, inter alia, Kollmann and Cote [1984] (Fig.4) widths greater than 3 mm. This curve also gives a great fit and a higher correlation coefficient.

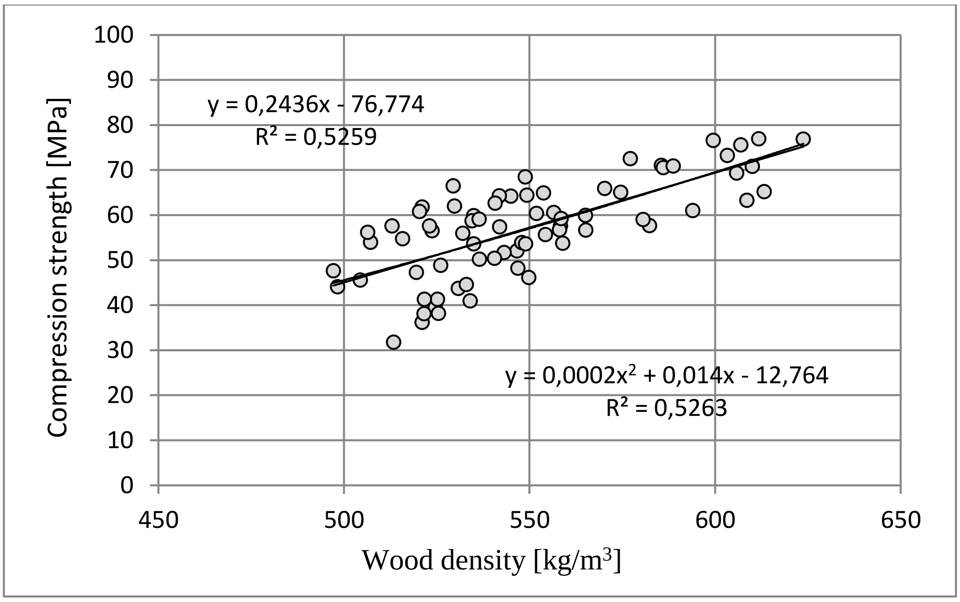

Figure5. The relationship between compresion strength along the fibres and wood density

The compression strength of wood along the fibers increased with growth of wood density [Wojciechowski, 1963; Cote and Kollman, 1968; Krzysik, 1978; Kozakiewicz, 2010; Jakubowski et al., 2013; Jankowska and Kozakiewicz, 2014; Kozakiewicz et al. 2020]. It is a directly proportional relationship. The correlation of the exponential curve is practically in line with the straight line (Fig.5). The coefficient of determination is high and amounts to 0.53, which means that the compressive strength is more than 50% dependent on the density of the wood. The simple correlation equation (slope) is close to the coefficient analogous dependence described for narrow-grain pine wood from Sweden [Vorreiter, 1949 [Kozakiewicz, 2010].

No correlation between the width of the annual growth ring and the compressive strength along the fibres was found [Rola et al. 2014]. The share of late wood alternately increased and decreased with the increasing value of compressive strength along the fibres [Rola et al. 2014]. This phenomenon may be due to the presence of reaction wood. The research showed only that the compressive strength along the fibres was 32-87 MPa while the share of late wood amounted to 30-45%. The obtained test results are of practical importance when assessing narrow annual rings Scots pine timber of the highest quality classes.

CONCLUSIONS

Based on the research on Scots pine wood (timber of first class from mature wood) the following conclusions were made:

1. The share of late wood was approximately constant in the entire analyzed density range (497 - 647 kg/m^3) and amounted to about 50%;
2. The dependence of pine wood density on the width of the rings, found in the research, is limited to narrow-grain wood.
3. The compressive strength along the grain increased with the density of the wood, and the relationship is strong.
4. No direct relationship was found between the compressive strength of wood in annual rings and the compressive strength along the fibres.
5. When assessing sawn timber based on annual rings increments, it is possible to indication its potential use and estimate the value based on this. Measurement of late wood in this context is useless (no correlation).

REFERENCES

BORYSIK P., KOZAKIEWICZ P., KRZOSEK S., 2019: Drzewne materiały konstrukcyjne. Wydawnictwo SGGW, Warszawa.

CHMIELOWSKI J., KOZAKIEWICZ P., BURACZYK W., 2018: Variability of annual rings and density of Scots pine (*Pinus sylvestris* L.) wood of Bolewice origin from the provenance surface in Rogów. Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology No 102, 2018: 11-15.

DZBEŃSKI W., 1984: Nieniszczące badania mechanicznych właściwości iglastej tarcicy konstrukcyjnej wybranymi metodami statycznymi i dynamicznymi. SSGW-AR, Warszawa.

DZBEŃSKI W., KOZAKIEWICZ P., KRUTUL D., HROL J., BELKOVA L., 2000: Niektóre właściwości fizyko-mechaniczne drewna sosny zwyczajnej (*Pinus sylvestris* L.) rogowskiej jako materiału porównawczego do badań na sośnie proweniencji łotewskiej. Materiały 14 Konferencji WTD SGGW „Drewno materiał wszechczasów". Rogów 13-15 listopada 2000: 31-36.

FABISIAK E., 2005: Zmienność podstawowych elementów anatomicznych i gęstości drewna wybranych gatunków drzew. Roczniki Akademii Rolniczej w Poznaniu – Rozprawy Naukowe 369. Wydawnictwo Akademii Rolniczej w Poznaniu, Poznań.

FORESTS IN POLAND 2018. Information Center of State Forests. ORWLP in Bedon. Warsaw.

GALEWSKI W., KORZENIOWSKI A., 1958: Atlas najważniejszych gatunków drewna. PWRiL, Warszawa.

ISO 13061-1:2014 Physical and mechanical properties of wood – Test methods for small clear wood specimens. Part 1: Determination of moisture content for physical and mechanical tests.

ISO 13061-2:2014 Physical and mechanical properties of wood – Test methods for small clear wood specimens. Part 2: Determination of density for physical and mechanical tests.

ISO/DIS 13061-17:2015 Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 17: Determination of ultimate stress in compression parallel to grain.

JAKUBOWSKI M., JELONEK T., TOMCZAK A., 2013: Gęstość drewna sosny zwyczajnej (*Pinus sylvestris* L.) jako wskaźnik odporności drzewa na działanie silnych wiatrów. Sylwan 157(7): 539-545

JANKOWSKA A., KOZAKIEWICZ P., 2014: Comparision of outdoor and artificial weathering using compressive properties. Wood Research 59(2): 2014, 245-252

KOLLMANN F., COTE W., 1984: Principles of Wood Science and Technology. Volume I: Solid Wood. Springer-Verlag. Berlin, Heidelberg, New York, Tokyo.

KOZAKIEWICZ P., 2010: Wpływ temperatury i wilgotności na wytrzymałość na ściskanie wzdłuż włókien wybranych rodzajów drewna o zróżnicowanej gęstości i budowie anatomicznej. Trzysta siedemdziesiąta pozycja serii - Rozprawy Naukowe i Monografie Wydawnictwo SGGW, Warszawa.

KOZAKIEWICZ P., 2013: Fizyka drewna w teorii i zadaniach. Wydawnictwo SGGW, Warszawa.

KOZAKIEWICZ P., 2019: Sosna zwyczajna (*Pinus sylvestris* L.) - polskie drewno. Przemysł Drzewny Research & Development nr 2/2019 (25), str. 72-77.

KRZOSEK S., MAŃKOWSKI P., 2013: Compression strength of pine wood (*Pinus sylvestris* L.) from selected forest regions in Poland, part II. Forestry and Wood Technology N. 83, 2013: 206-210

KOZAKIEWICZ P., JANKOWSKA A., MAMIŃSKI M., MARCISZEWSKA K., CIURZYCKI W., TULIK M., 2020: The wood of Scots Pine (*Pinus sylvestris* L.) from Post-Agricultural Lands has Suitable Properties for the Timber Industry. Forests 2020,11, 1033: doi:10.3390/f11101033

KRZYSIK F., 1978: Nauka o drewnie. PWN, Warszawa.

PN-D-04100:1977 Oznaczanie wilgotności.

PN-D-04101:1977 Oznaczanie gęstości.

PN-D-04102:1979 Oznaczanie wytrzymałości na ściskanie wzdłuż włókien

PN-D-04110:1955 Fizyczne i mechaniczne własności drewna. Badanie procentowego udziału drewna wczesnego i późnego.

PN-D-96000:1975 Tarcica iglasta ogólnego przeznaczenia.

ROLA P., SEKRECKI P., STANISZEWSKI P., TOMUSIAK R., WYSOCKA N.,2014: Strukturalne właściwości drewna sosny zwyczajnej (*Pinus sylvestris* L.) w zależności od strony świata - wstępne wyniki badań. Studia i Materiały CEPL w Rogowie, R.16. Zeszyt 40.

TIEMANN H. D., 1951: Wood technology: constructions, properties and uses. Pitman Publishing Corporation, New York, Chicago.

VORREITER L., 1949: Holztechnologisches Handbuch. Band I: Allgemeines, Holzkunde, Holzschutz und Holzvergütung. Verlag Georg Fromme & Co. in Wien.

Streszczenie: *Zależność między wytrzymałością na ściskanie wzdłuż włókien a szerokością przyrostów rocznych w wysokiej jakości partii tarcicy drewna sosny zwyczajnej* (*Pinus sylvestris* L.). W Polsce dominującym gatunkiem w drzewostanach i najczęściej wykorzystywanym drewnem na potrzeby przemysłu drzewnego jest sosna zwyczajna.

W praktyce przemysłowej po przerobieniu drewna na tarcicę zwykle nie jest już znane jej pochodnie (w większości przypadków nie prowadzi się w przerobie takiej ewidencji tj. przyporządkowania drewna do jego pochodzenia). W ramach niniejszej pracy zbadano czy znane zależności między wybranymi cechami sosny są również spełnione w drewnie z partii tarcicy ogólnego przeznaczenia (tarcicy bezsęcznej, najwyższej jakości pozyskanej z drewna dojrzałego) i mógłby stanowić pomoc w sortowaniu i tym samym ocenie wartości drewna.

W przeprowadzonych badaniach wykazano, że przy ocenie tarcicy na postawie szerokości przyrostów rocznych można wnioskować o jej gęstości oraz na podstawie gęstości oszacować wytrzymałość na ściskanie wzdłuż włókien. Pomiar udziału drewna późnego w tym kontekście jest nieużyteczny (brak istotnej korelacji).

Corresponding author:

Paweł Kozakiewicz ✉
Department of Wood Sciences and Wood Preservation
Institute of Wood Sciences and Furniture
Warsaw University of Life Sciences – SGGW
166 Nowoursynowska St.
02-787 Warsaw, Poland
e-mail: pawel_kozkiewicz@sggw.edu.pl
http://pawel_kozakiewicz.users.sggw.pl
phone: +48 22 59 38 647